Proceedings of the 26th Annual British Columbia Mine Reclamation Symposium in Dawson Creek, BC, 2002.
The Technical and Research Committee on Reclamation

THIRTY YEARS OF RECLAMATION RESEARCH IN THE ALPINE AND SUBALPINE REGIONS NEAR GRANDE CACHE, ALBERTA

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ABSTRACT

The Alberta Research Council, Inc. (ARC) has conducted a surface coal mine reclamation research program in association with the operations of Smoky River Coal Ltd. near Grande Cache, Alberta since 1971. The main objective of this long-term study was to develop and refine cost-effective methods of establishing a self-sustaining vegetation cover that is in harmony with adjacent undisturbed areas.

Soil handling practice development involved the completion of soil surveys and recommendations regarding soil salvage strategies in these regions where salvageable soil materials are minimal to non-existent. Recommendations pertinent to coversoil replacement strategies were developed.

Plot studies to determine the suitability and adaptability of various agronomic and native grasses and legumes as well as fertilization trials were established and monitored annually. In the early 1970's the lack of native seed necessitated the use of introduced species for large scale operational revegetation work in the subalpine region. Long-term monitoring results indicated that desirable introduced species will thrive and reproduce at these elevations and that native herbaceous species as well as trees and shrubs will invade the revegetated areas. Revegetation research activities in the alpine involved the use of native grasses and legumes indigenous to the area. Container and bare root conifer seedlings and cuttings of deciduous species were utilized initially to establish trees and shrubs in the subalpine. Direct seeding has also proven to be a viable method for establishment of trees and shrubs in the subalpine.

Automated climate monitoring stations were installed at different elevations at three locations in the study area yielding data that support the conclusion that climate is the most limiting factor to reclamation success in the subalpine and alpine regions.

Research results were transferred to the operational scale throughout the term of the study. Recommendations regarding appropriate reclamation practices for the regions including soil salvage and replacement strategies, revegetation techniques and successional processes have been developed. The success of reclamation in the study area is measured by the "productivity" achieved and the presence of and utilization by wildlife.

INTRODUCTION

Industrial development and recreational use are rapidly expanding in the subalpine and alpine regions of North America (Macyk, 2000a). In light of this expanding pressure for development, the major challenge is not to withdraw these areas from reasonable use, but to develop and refine the techniques to return these ecosystems to a natural self-sustaining state (Brown et al., 1978). Reclamation of disturbed areas in the alpine and subalpine represents a major challenge due to the severe climate and relatively limited soil resource compared to other ecoregions (Macyk, 2000a).

In 1972, Mclntyre Porcupine Mines Limited, the original mine operator in the Grande Cache area, commissioned the Alberta Research Council Inc. (ARC) to establish a reclamation research study. Coal production from the original No. 8 Mine began in June 1971, and reclamation research followed. In 1976, a similar study began at the No. 9 Mine. In 1992, a project to evaluate the potential for revegetating mined land in a proposed No. 12 Mine south area in the alpine was initiated. The research program continued in cooperation with Smoky River Coal Limited until March 2000.

When the ARC undertook the study, reclamation research was in its infancy in Alberta. Techniques used elsewhere at the time, primarily in the eastern United States, were not applicable in Alberta. Legislation pertinent to reclamation in Alberta was not formally in place until the Land Surface Conservation and Reclamation Act of 1973 and the Coal Policy of 1976 (Macyk, 2000b).

OBJECTIVES

The initial objective of the study was to determine methods of establishing a long-term vegetation cover that is in harmony with adjacent undisturbed areas by:

- characterizing unmined and reconstructed soils and evaluating their suitability for reclamation;
- determining suitable grasses and legumes for establishing a protective vegetation cover on reclaimed areas to minimize erosion; and,
- determining the nutrient requirements for maintaining a viable vegetation cover.

The work conducted focused on developing and implementing cost-effective techniques for reclamation that meet the requirements of regulatory agencies. Because this study was ongoing for a relatively long time, new objectives were added as additional needs were identified. Modifications were made to the conclusions and recommendations developed as the length of record increased and more data became available. The long-term monitoring allowed for the development of recommendations for the operational reclamation practices in the Grande Cache area.

STUDY METHODS

Soils

The unmined soils in the No. 8 and No. 9 Mine areas were dominantly Luvisolic and Brunisolic (Canada Soil Survey Committee 1978). The depth of salvageable material overlying bedrock ranged from 10 cm to

1 m. The unmined soils were moderately to slightly acid, medium textured, and had low levels of available plant nutrients, especially nitrogen and phosphorus.

Soil salvage was an integral part of the materials handling program associated with the mining operation. Following the removal of merchantable timber, the soil overlying consolidated bedrock was removed in one lift, incorporating a minimum amount of coarse fragments. The soil materials were stockpiled for future use. Because the surface or organo-mineral horizons were minimal or nonexistent, and the sola varied in thickness, segregation or selective handling of soil materials was not considered. Soil material was replaced on the spoil surface following the removal of overburden and coal and subsequent backfilling and grading.

Practical soil salvage guidelines were developed along with a description of the procedures that should be followed to ensure that the limited soil resource available is managed effectively. The guiding principles are:

- soil quality is more important than soil quantity;
- the salvage process involves the removal of suitable soil material from as large an area as possible rather than removal of suitable and less suitable material from a smaller area to achieve the required volume needed for replacement;
- coarse fragment or rock content in the salvaged soil should be minimized. It is recognized that it is impossible to eliminate them completely due to the nature of the soils in the area; and,
- the maximum slope that allows for the efficient use of equipment for soil salvage is about 27 degrees.

Salvaging and replacing soils in areas to be mined and reclaimed results in a reconstructed surface soil horizon which reflects a blending of soil characteristics found in pre-mining soil horizons. The reconstructed soils that were developed did not duplicate the soils that had existed before disturbance. The mining process most dramatically altered the physical properties of the soils. The data indicated that, compared with unmined soils, reconstructed soils had a coarser texture, higher pH, and lower levels of available plant nutrients.

The silt loam texture and low levels of organic matter resulted in a crusting problem, which has a direct bearing on infiltration capacity, and processes, such as runoff and erosion. Infiltration tests indicated that the undisturbed soils had considerably higher infiltration rates than the reconstructed soils. Although these reconstructed soils have some limitations, with proper management they are critical in achieving reclamation success.

Vegetation Establishment

The land use goal of reclamation in the area is to develop a landscape that has equivalent productive capability (Macyk 2000b). Overall the intent is to re-establish a diverse vegetation cover that is dominantly forest with a capability for wildlife use and a cover that provides erosion control.

In May 1972, vegetation work in the subalpine was initiated by establishing three research plot areas with slopes ranging from 0 to 40°. The three locations included 60 individual 6 m x 9 m plots to determine the suitability of 30 different agronomic grasses and legumes. Over the years a total of 43 different plot areas were established to assess revegetation in the subalpine portion of the overall mined area.

The experimental site in the alpine was established in July 1992 and located outside the boundary of the area to be mined to preserve the integrity of the site. This allowed for an adequate record of data to provide a basis for conclusive recommendations. The two plot areas are located on a gentle southwest facing slope which represents the most difficult slope position to reclaim in this region.

Two different surface or growth medium materials including "coversoil" or the surface soil material and the "rock spoil" material were used. The coversoil plot area was constructed by first removing the surface soil layer (12 to 18 cm) and then excavating and mixing the underlying spoil material to a depth of about 1.5 m. The mixed spoil was levelled and the coversoil replaced on the spoil surface (Macyk et al., 1998).

The rock spoil plot area was constructed by excavating and mixing the weathered rock material to a depth of about 1.2 m. There was no surface soil present in the area prior to disturbance resulting in a growth medium comprised of fragmented rock and the associated fines. Both the "coversoil" and "rock spoil" materials are typical of the area and are representative of the reconstructed surface that occurs following surface mining activities. A total of 18 plots (4 m x 8 m) was established at each of the two locations. The rock spoil plot treatment group is located about 300 m north of the coversoil plot treatment group. A wire mesh fence approximately 2 m in height was constructed at each of the two plot areas to protect the plots from all terrain vehicle traffic (Macyk et. al., 1998).

In addition to the effect of the different surface material characteristics, species type was the other major variable included in the experiment. Grass seed was obtained from native plant researchers at the Alberta Environmental Centre and a commercial seed supplier. The species included alpine bluegrass *(Poa alpina)* seeded at 110 g/plot, Highlander slender wheatgrass *(Agropyron trachycaulum),* Mountaineer broadglumed wheatgrass *(Agropyron violaceum),* and sheep fescue *(Festuca ovina)* each seeded at 175 g/plot.

Plot seeding was completed September 1 and 2, 1992. Raking was completed immediately after seeding of each plot. Selected plots were fertilized with the equivalent of 125 kg/ha of 35-15-0 in June 1993. The plot treatments were replicated three times at each of the two locations with the exception of the control and sheep fescue treatments.

Native Species

Using native species in reclamation was addressed early in the study. Native species were considered because:

- animals might prefer them;
- less maintenance might be required after they are established; and,
- native species are more aesthetically pleasing.

In 1972, native seed was not available commercially. Consequently seeds from the following species were collected in the undisturbed portions of the mine area and subsequently cleaned and planted:

- silky locoweed *(Oxytropis sericea);*
- showy locoweed *(Oxytropis splenders);*
- alpine hedysarum *(Hedysarum alpinum);*
- lupine *(Lupinus* spp.); and,
- hairy wildrye *(Elymus innovatus).*

In 1986, factors affecting native species invasion were evaluated at the No. 8 Mine (Van Zalingen et al., 1988). Sampling point locations were predetermined by randomly applying a 60 m interval grid pattern to a 1:3000 aerial photograph of the site. Grid intersections were taken as individual sampling points. At each of the 220 sample point locations, a 10 m tape was laid out due west and 20 x 50 cm (Daubenmire) frames were placed at the 2, 4, 6, 8 and 10 m points. Visual estimates of percent cover (aerial) were recorded for each species present within the frames. Additional data recorded for each sampling location included percent slope, aspect (degrees), and an estimate of coarse fragments and coal waste present. Percent coarse fragments were recorded by class including 0 (0 to 1% cover), 1 (2 to 5% cover), 2 (6 to 20% cover), and 3 (>20% cover).

Data used in statistical analyses included that collected on the site and additional data available from previous site studies by ARC, including fertilization and seeding treatments, coversoil depth, distance from the nearest undisturbed area, and distance from the nearest upwind undisturbed area. The statistical analyses of data consisted primarily of covariance analyses. Dependent variables were percent cover values for native species identified within Daubenmire frames. Independent variables included percent slope, aspect, coversoil depth, fertilization and seeding treatments, number of times fertilized, number of times seeded, coarse fragment rating, coal waste rating, distance from the nearest undisturbed area, and distance from the nearest upwind seed source.

Coarse fragment and coal waste ratings were treated as class variables.

Tree and Shrub Establishment

The study assessed the growth of native trees and shrubs on reclaimed land relative to meeting the objective of establishing a long-term cover in harmony with the surrounding area. As seedlings suitable for planting above an elevation of 1100 m were unavailable, a cone collection program was undertaken. Seedlings of lodgepole pine *(Pinus contorta* var. *latifolia),* englemann spruce *(Picea engelmannii),* and white spruce *(Picea glauca)* were reared in a greenhouse. Different sizes and types of containers were used to determine those containers most suitable for production of seedlings for planting in reconstructed soils and to assess the relative costs associated with seedling production.

Branch cuttings of willow *(Salix* spp.) and balsam poplar *(Populus balsamifera)* and root cuttings of aspen *(Populus temuloides)* were rooted in the greenhouse. Direct planting methods were also used for willow cuttings. Most of the materials were planted at reclaimed sites with an established grass, or grass and legume cover.

During the monitoring of tree seedling survival and growth, some of the seedlings demonstrating poor growth had limited root egress. Also, frost heaving of some of the container seedlings resulted in the upper root mass being exposed above the soil surface, resulting in many of the seedlings dying. Additional problems included the difficulty in planting bare root and container seedlings in the reconstructed soils at the site, and the cost of production and planting. As a result a direct seeding program was implemented in 1983 to assess this technique for use on an operational scale.

Climate Monitoring

Climate monitoring is an important component of a reclamation research program. The data obtained in this study helps reclamation planning and provides an insight into the effectiveness of the reconstructed landscape and overall vegetation performance. For example, rainfall measurement provides an understanding of the amount of precipitation that occurs during the growing season. More importantly, it provides information on rainfall distribution and intensity throughout the growing season. Rainfall distribution data enables one to determine optimum times for seeding and planting and predict periods of less than optimum precipitation, and ultimately soil moisture conditions.

Climate monitoring began in 1973 and continued until March 2000. The types of equipment used changed with time as the technology improved and monitoring locations were added as mining advanced. The parameters measured included air temperature, soil temperature, rainfall, wind speed, wind direction, relative humidity, solar radiation, and soil moisture. Measurements occurred at three-minute intervals, and minimum, maximum and mean values were recorded hourly.

Precipitation records were maintained on a growing season basis. The measurements included collection of total rainfall data as well as use of tipping bucket units to obtain rainfall distribution and intensity data. Rainfall intensity data has provided insight into the ability of reconstructed soils to absorb water or allow infiltration to occur and the potential for runoff and erosion to occur.

RESULTS AND DISCUSSION

Agronomic Grasses and Legumes

An initial concern was that legumes, particularly alfalfa, would not adapt or survive at the elevations in this study. However, most of the agronomic grasses and legumes initially planted have survived, and continue to thrive. Many of the species produced and dropped viable seed. All of the introduced or agronomic species used are suitable for reclamation in the subalpine.

For reclamation planning in the Grande Cache area, annual growth monitoring over time indicated species suitability desirability, stand composition, and fertilizer requirements.

For example, with time and withholding of fertilizer, alfalfa increased its share of the ground cover, while grasses, which were the major component of the initial cover in a mixed stand, declined in vigour. Several recommended seed mixtures and seeding rates appropriate for different slope aspects (moisture regimes) were developed and documented. Spring is generally the most suitable time of year for planting because legumes, which should be included for good initial cover establishment, perform much better when seeded in the spring.

Native Species

Results of the initial subalpine work indicated that the seed of some of the native grasses and legumes collected had relatively low germination rates. For example, the germination rate for locoweed was 70%, while the rate for alpine hedysarum was only 15%. A viable erosion control cover using only native species took at least two years longer to become established than when agronomic species were used. Despite some of the limitations associated with using native species, the species used in the program are considered appropriate for large-scale use. Acquiring an adequate seed supply can be a limitation for revegetation with at least some of the native species.

Following plot seeding at the alpine site in September 1992, germination and emergence were well underway in both the rock spoil and coversoil plot areas by mid-June 1993. Substantial growth was achieved in 1994 and continued through 1999. The alpine bluegrass, sheep fescue, and broadglumed wheatgrass dropped mature seed each year from 1995 through 1999.

The plant cover established varied with the different species in both the rock spoil and coversoil plot areas. The obvious difference in growth of the various species between the two areas related particularly to the height, and to a lesser extent the density of the cover. Cover was less dense at the rock spoil plots because of the higher course fragment content and smaller number of potential germination sites. Data obtained in 1999 indicated that ground cover was greater at the coversoil than the rock spoil sites for all species. The overall mean for the percent cover at the coversoil plots was 83% compared to 78% for the adjacent undisturbed area. The control plot which had no seed applied had developed a plant cover of 85%. The overall mean for the percent cover at the rock spoil plots was 64% compared to 67% for the adjacent undisturbed area. The control plot which had no seed applied had developed a plant cover of 29%.

In terms of species performance, including drought tolerance and seed set, the broadglumed wheatgrass appeared to be the best performer followed closely by alpine bluegrass and then the sheep fescue and slender wheatgrass.

Fertilizer Requirements

The available nutrient levels of the undisturbed and reconstructed soils in the subalpine were low. Grasses and legumes showed a marked response to fertilizers at the fertilized plots and produced 10 to 20 times more dry plant matter than the unfertilized plots.

The major concern about using fertilizers in reclamation was that large applications of fertilizer would be required annually to maintain the established cover. Furthermore, the vegetation cover established with the aid of fertilizers in the subalpine experimental areas was relatively dense, which raised concerns about precluding invasion by native species and creating a fire hazard as a result of the buildup of dead plant material. The dead plant material probably does not create a fire hazard, but on balance, is considered useful for improving the organic matter status of the reconstructed soil. Long-term observations have shown that refertilization is not required annually to maintain a variable vegetative cover.

The application of fertilizer at the alpine plots in 1993 resulted in increased germination and enhanced growth at both plot areas with a more visible impact at the rock spoil site than the coversoil site. The cover in the fertilized plots had greener, larger, and generally more lush plants (Macyk et al., 1998). In comparison, the plants in the unfertilized plots were shorter, more spindly (thinner), and slightly chlorotic in appearance. This was expected since the coversoil material had higher natural fertility levels than the rock spoil. In addition to the more enhanced growth at the rock spoil plots, the fertilizer also had a direct bearing on plant maturity. This indicated an earlier start to plant function and growth in the spring and/or more rapid progression of plant development during the growing season. The growth at the coversoil plots was quite evident in 1993 with lesser impact in 1994 and in subsequent years. This was expected as the initial fertilizer application rates were relatively low and plant uptake and losses due to leaching would eventually deplete the nutrients added. Observations in 1999 indicated that the fertilized treatment did not exhibit better plant vigour or cover density than the not fertilized treatments confirming that the initial effects of fertilization had diminished over the five seasons since it was initially applied. These results suggest that an initial fertilizer application will enhance initial vegetation establishment and that subsequent applications will not likely be required.

Native Species Invasion

In 1986, sixty unseeded species, including eight native legumes, were identified at the No. 8 Mine subalpine study site. Statistical analyses were undertaken to assess the parameters measured, and these parameters or variables were ranked to determine their relative importance.

The distance from the nearest westerly undisturbed area significantly influenced the distribution of native species in the area. Except for moss, all native species exhibited a decline in percent cover, with increasing distance from the nearest westerly undisturbed area. The independent variables were ranked in order of importance, as follows:

- coarse fragment rating of the reconstructed soil;
- northwest versus southeast aspect and distance from the nearest westerly undisturbed area;
- percent cover of alfalfa;
- percent slope; and
- soil depth.

Invasion or encroachment of native species into the plot areas at the alpine site has been documented since the time that the plots were established. The rock spoil plots had an overall mean of 187 plants per plot compared to 123 plants per plot in the coversoil plots in 1999. This difference between the two areas or materials can be attributed in part to the fact that the grass cover is more dense in the coversoil plots resulting in less germination sites for invading natives. Also, many of the species identified appear to have a preference for the rock spoil material and its associated microclimate.

Tree and Shrub Performance

Trees and shrubs were established successfully and thrive in areas initially seeded to grasses and legumes. Seedlings growing in association with alfalfa appeared healthier and more vigorous than those growing in association with grasses. The practice of planting seedlings in grassy areas was questioned initially because of the expected competition for moisture. However, the protection afforded the seedlings by the grass and legume cover, especially in holding snow in the winter, far outweighs the negative aspects of moisture competition during the growing season. Climatic factors dictate that some form of protection for the young seedlings is critical in this region. During the winter, it is not unusual to have the snow cover blown off by strong winds or melted down during periods of warm weather. Subsequent cold spells, especially if accompanied by strong winds, can be particularly harmful to young seedlings. Winds averaging 60 to 70 km/h for six to eight hours a day are not unusual during the winter. During the summer, surface and near surface soil temperatures can be over 45 to 50°C for several hours on consecutive days.

The trees growing in the reclaimed area were at least comparable to those in the reforested and the undisturbed forest settings, based on comparisons of the growth of pine and spruce from 1983 to 1999 (Macyk and Pojasok, 2000).

The program demonstrated that direct seeding is a viable alternative to using seedlings in some locations. The direct seeding trials demonstrated that:

- pine germinants outnumbered the spruce for both spring and fall seeding;
- spruce seeded in spring resulted in virtually no germinants; and
- pine seeded in the fall resulted in a four- to ten-fold increase in germinants compared to spring seeding.

Climate Monitoring Data

The climate monitoring data obtained provided an insight into the effectiveness of the reconstructed landscape and overall vegetation performance, and assisted in reclamation planning. Understanding the distribution of rainfall during the growing season has helped to develop recommendations for the optimum time for seeding and planting and the periods when less than optimum precipitation and, ultimately, soil moisture conditions are likely to prevail.

Soil temperature data has provided the basis for decision making regarding locations where planting of tree seedlings should not be undertaken due to high surface soil temperatures. Wind speed and direction data contributed to revegetation strategies that take into account the dynamics of native seed dispersion and the effects of snow cover removal in some areas, and the related need for adequate ground cover to protect susceptible species, such as newly planted tree seedlings.

The long-term climate record associated with this program provides a firm basis for reclamation planning and long-term site management. An example of the importance of understanding the climatic and landscape dynamics in reclamation planning is illustrated by comparing east-facing slopes, which are sheltered and support a dense herbaceous and tree cover, and the exposed west-facing slopes, which are windswept and support a sparser vegetation cover. Revegetation planning for the two areas will be different, with more emphasis on a hardy grass and legume cover and less emphasis on trees and shrubs for the west-facing location.

CONCLUSION

Reclamation in the alpine and subalpine regions can be successful provided that appropriate procedures are adopted. Soil management and the selection of suitable agronomic and native species aided by natural processes will result in the establishment of diverse plant communities and allow for different land use options.

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